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FURTHER PROGRESS

IN DEVELOPMENT OF A

PERFORMANCE-BASED TEST

OF GAZE CONTROL CAPABILITY

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A performance-based test of gaze capability has been developed using low-cost light-emitting-diode (LED) displays operated under the semi-automated control of a desk top micro-computer. The test is based on the ability of an individual to rapidly shift his gaze over a relatively large angle and precisely identify digits presented in a numeric array for brief, time-varied exposure times. The new test, involving four widely-spaced displays, allows the derivation of performance scores for gaze shifts involving head movements made in the left, right, up, and down directions. The results of three experiments involving Navy and Marine Corps flight candidates as subjects, support the original report findings relative to the heavy influence of exposure time on performance, and most importantly, the wide range of performance capabilities reflected within the study population. This latter point has the potential for operational significance in that the test should distinguish pilots with exceptional gaze capabilities from those with relatively poor gaze performance. Required Directions in Applicators, (A)

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SUMMARY PAGE

THE PROBLEM

In the military cockpit, frequent small and large gaze shifts are required to visually scan and monitor a variety of flight instruments and avionics systems. When gaze shifts are large, precise coordination between head and eye movements is required to rapidly fixate on a new visual target. Relatively sophisticated transducers and related instrumentation are often used to assess gaze-shift efficiency. Since these procedures are generally expensive and time consuming, this laboratory has initiated research to develop a relatively low-cost, performance-based measure of head/eye coordination during large gaze shifts that are important to in-flight pilot performance. A previous report described the theoretical basis for the gaze test and presented data for small and large unidirectional head motions. This report describes further progress in the development of such a test.

FINDINGS

A performance-based test of gaze capability has been developed using low-cost light-emitting-diode (LED) displays operated under the semi-automated control of a desk top microcomputer. The test is based on the ability of an individual to rapidly shift his gaze over a relatively large angle and precisely identify digits presented in a numeric array for brief, time-varied exposure times. The new test, involving four widely spaced displays, allows the derivation of performance scores for gaze shifts involving head movements made in the left, right, up, and down directions. The results of four experiments, involving Navy and Marine Corps flight candidates as subjects, support the original report findings relative to the heavy influence of exposure time on performance, and most importantly, the wide range of performance capabilities reflected within the study population. This latter point has the potential for operational significance in that the test should distinguish pilots with exceptional gaze capabilities from those with relatively poor gaze performance.

RECOMMENDATIONS

The present configuration of this test of gaze function produces performance scores for four different exposure times for each direction of head movement. Although the test meets the basic objectives of this research program relative to cost and ease of operation, the extent of the information gained from the test probably exceeds that required for an approximate measure of gaze function. To simplify the test and increase its clinical potential, we recommend that the test be further refined by using a Bekesy-type determination of a threshold time for recognition of a fixed number of digits. This development would reduce the time required to conduct the test and would yield a single performance score for each direction of head movement.

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INTRODUCTION

In the military cockpit, visual scanning and monitoring of different flight instruments and avionics systems requires frequent gaze shifts, some exceeding $100°$ (1). Such gaze shifts require close coordination between head and eye movements in order to achieve rapid fixation on the new visual target. Typically, head and eye velocities are summed, moment-by-moment, to yield remarkably constant gaze velocity, even though neither the head nor the eye velocity remains constant (2). For example, saccadic eye velocity generally slows and then reverses direction when the head continues to turn after the eye has acquired a target. Yet, gaze velocity remains constant during the saccade and stops after the saccade is completed.

A number of mechanisms are involved in this coordination. One widely accepted hypothesis is that the vestibulo-ocular-reflex (VOR) modifies eye velocity to automatically maintain the close eye-head coordination required for the eye to acquire and hold a target during head movement (3,4,5). A recent alternative hypothesis is that two different motor programs are involved during large gaze shifts; one to generate the large ocular saccade and the other to perform the function often attributed to the VOR (6,7,8). According to this viewpoint, the VOR "turns off" during large saccades but is operative during smaller shifts in gaze.

Whatever the outcome of this interesting question concerning mechanisms of eye-head coordination, efficient gaze-shift control is an important element of pilot performance in modern military aircraft. In this light, our activity has initiated research (2) directed at developing a low-cost, performance-based test of gaze capability. The initial data from this research indicated a substantial range of performance on a task requiring rapid acquisition of visual information following large gaze shifts. The range of performance differences observed would potentially provide some pilots with a functional advantage over others in an operational environment. This aspect of visual performance can be degraded, even more, by peripheral or central nervous system disorders. However, it is well established that adaptive mechanisms can be quite effective in overcoming limitations in eye-head coordination (4). A long-term objective of the performance-based testing program is to provide insight as to whether such adaptive mechanisms can compensate disorders and reestablish requisite performance.

In the previous study (2), the procedure consisted of a presentation of a series of individual fixation letters on a CRT, followed by brief, time-varied presentations of digit arrays on a second CRT display located a known angular displacement from the first display. Serial letter identification was used to maintain initial gaze position, and performance was scored as the number of digits correctly identified in proper sequence following presentation of visual and auditory signals to initiate gaze shift from the fixation display to the digit array display. Only part of the study involved head and eye movements, and these head-eye gaze shifts involved motion in the horizontal plane in only one direction. The present study extends this initial research effort by providing performance data for both left- and right-directed shifts in gaze made in the horizontal plane as well as up- and down-directed shifts made in the vertical plane.

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In addition, light-emitting diode (LED) displays were substituted for the higher cost CRT displays used in the first study.

The paper presents the results of four distinct, but related, experiments. The first experiment evaluated the performance of subjects making 60° head movements in the horizontal plane using an LED display with relatively small alphanumeric characters. The second experiment used larger LED displays separated by 90°. In the third experiment, performance was measured for head movements made in the vertical as well as horizontal head planes using the large displays. The last experiment involved the repeat testing of a small group of subjects to investigate the extent of learning or practice effects associated with the test.

The long-term objective of this research remains to develop a simple, inexpensive performance-based screening procedure to facilitate comparison of initial abilities with subsequent operational performance and to assess changes in this component as a result of practice, age, operational experience, and/or recovery from disorders affecting gaze shift control.

EXPERIMENTAL EQUIPMENT AND PROCEDURES

The equipment, stimulus conditions, and test protocol for the current test closely follow those used in the original study (2). Minor differences exist relative to the number of digits used in the numeric stimulus array, the fixation letter on-off display times, character size and spacing, and display intensity.

EQUIPMENT

Experiment 1

The device used to display the visual stimulus was a small-scale combination input/output RS-232 terminal (Burr Brown Research Corporation Model TM71 Microterminal). The display component of the device was a 16-character light-emitting diode (LED) with character generation deriving from a 16-segment font. The character height was approximately 2.84 mm (0.112 in), and the center-to-center distance between characters was approximately 4.44 mm (0.175 in). With the font segments used to generate the numeric characters, the characters were approximately 1.4 mm (0.055 in) wide resulting in an inter-digit spacing of approximately 3.04 mm (0.12 in) between the end of one digit and the beginning of the next digit. At a 1-m viewing distance, these dimensions result in viewing angles for character height, character width, and inter-digit spacing of approximately 9.8, 4.8, and 10.5 min, respectively.

The luminance of the display characters was measured with a commercial photometer (Photo Research SPECTRA Prichard Photometer, Model 1980A) using two different measurement techniques. In the first technique, the instrument was set up to measure the luminance of a single segment of the display font. The setup of the photometer was as follows: the face of the display device was positioned 4.12 cm (1.625 in) from the face of a Micro-Spectra FL-19 supplementary lens. With the filter turret open and a 2-min angular measurement field positioned to be within the width of a single vertical LED line segment, the luminance was measured as 144 cd/m^2. The second

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procedure involved measuring the average luminance of the alphanumeric characters using a SL-40 lens placed 76.2 cm (37 in) from the display. A 20-min angular measuring field was positioned so that its diameter equaled the height of the characters and completely circled a single character. The luminance of each of the 22 alpha characters was then measured with the filter turret open and an over-all mean calculated indicating an average luminance of 8.2 cd/m^2. The same technique applied to the eight numeric characters indicated a mean luminance of approximately 7.4 cd/m^2. Immediately after presenting the eight-digit stimulus array for a given exposure period, the digits were masked with eight zeros, each of which had a measured luminance of 8.6 cd/m^2.

Experiments 2, 3, and 4

In these experiments, visual stimuli were presented by a larger display module (Burr Brown Research Corporation Model TM27 Microterminal). This LED display had an eight-character display capability based upon a hexidecimal format with character generation deriving from a seven-segment font. The characters generated with this font had the following approximate dimensions: height- 7.62 mm (0.30 in), width- 5.2 mm (0.2 in), and an inter-digit spacing of about 5.0 mm (0.2 in) between the end of one character and the beginning of the next character. At a 1-m viewing distance, these dimensions result in viewing angles for character height, width, and inter-digit spacing of approximately 26.2, 17.8, and 17.1 min, respectively. The ratio of stroke width (width of a single LED line segment) to character height was approximately 1:8.

The luminance of the display characters was measured with the same equipment and measurement techniques used for Experiment 1. The setup of the photometer to measure the luminance of a single segment of the display was as follows: the face of the display device was positioned 4.12 cm (1.625 in) from the face of a Micro-Spectra FL-19 supplementary lens. With the filter turret open and a 2 min angular measurement field positioned to be within the width of a single vertical LED line segment, the luminance was measured as 17.4 cd/m^2. The average luminance of the alphanumeric characters was measured using a SL-40 lens placed 68 cm (27 in) from the face of the display. A 1.0° angular measuring field was positioned so that its diameter equaled the height of the characters and completely circled a single character. The luminance of each of the three alpha characters was then measured with the filter turret open and an over-all mean calculated indicating an average luminance of 1.36 cd/m^2. The same technique applied to the eight numeric characters indicated a mean luminance of the same value. The luminance of each of the eight zeroes used to mask the numeric display was measured as 1.58 cd/m^2.

The TM27 display module was powered from a separate DC power supply that was adjusted for a 7.6-volt output prior to making the luminance measurements. Photometer measurements made at different operating voltages indicated a linear relationship between luminance and voltage. For example, the luminance of the "8" character varied linearly from 1.57 cd/m^2 at 7.6 volts to 3.28 cd/m^2 at 10.0 volts.

STIMULI GENERATION

Experiments 1, 2, 3, and 4

A desk top computer (Hewlett Packard Model 9845C) was used to generate and store the test stimuli and to control the LED displays during a testing session. The letters A, C, and E served as fixation characters in all experiments. In the process used to randomize presentation of the fixation characters, sequences that involved two identical consecutive characters were eliminated. The number of single fixation characters sequentially presented was also randomized over the range of two to four characters where the display of each character was marked by a 200 ms "on" period followed by a 400 ms "off" (blank screen) period. Immediately after presentation of the last fixation character on the first display, an acoustic tone signaled the subject to begin head movement toward the second display. At the same instant, the eight-digit stimulus array was presented on the second display for a preselected exposure time.

With the eight-character numeric display, only digits two through nine were included in the stimulus array. In the randomization process, sequences that involved two adjacent digits of the same value were eliminated. In addition, components of the stimulus array that involved three sequential digits that produced a single-step run in either the up (e.g., digits 4,5,6) or down (e.g., digits 8,7,6) direction were eliminated. Four different exposure times were used to display the numeric array where time was measured from the instant the audio tone was completed to the instant the numeric display was turned off by the visual mask.

Significant exposure time errors can be introduced as a result of computer software delays. To determine the extent of these errors, the actual exposure times were measured using a photocell and timing oscilloscope. The time difference between the observed and desired exposure times was then used as a time correction factor in the setup of the computer clock.

Exposure time sequences were randomized with each exposure time presented the same number of times for each direction of head movement. In addition, the number of fixation letters preceding presentation of the numeric array was adjusted so that each exposure time received the same number of two, three, and four letter fixation sequences. Upon completion of the randomization process, the entire test configuration was stored on disk so that subjects could be tested under identical stimulus conditions.

TEST PROTOCOL

Experiment 1

The subject was seated in a dimly illuminated testing room containing the two display modules. One module was located at eye level 30° to the left of the subject; the other was 30° to the right. The 30° angular displacements were measured from the visual dead ahead position to the leftmost digit presented on a given display. Before beginning the test, written and verbal descriptions of the testing procedure were presented to the subject in detail. In essence, the subject was instructed to directly face the visual display module that contained a dash character in the

leftmost character position and signified that the test was about to begin. The randomized, single-character, fixation letters were then sequentially presented followed by a brief audio tone. At this instant, the randomized eight-digit numeric stimulus was presented on the second display for pre-selected exposure times of 500, 750, 1000, and 1250 ms. At the end of the exposure time interval, the numeric stimulus was masked by eight zeros displayed for 500 ms. The mask was then followed by the display of a single dash character, which signified that the next test trial would start with the presentation of the fixation letters on this display.

The subject's task was to call out each of the fixation characters as they appeared. At the sound of the audio tone, the subject rapidly rotated his head toward the second display and called out as many of the displayed digits he recognized in proper left-to-right sequence. The subject was instructed to call out the digits individually (e.g., if the subject could correctly identify four digits such as 3564, he was to call out "three, five, six, four" not three thousand five hundred and sixty-four or some equivalent variation). Performance was scored as the number of digits correctly identified in proper sequence with the exception that a score of zero would be given if the alpha fixation characters were not correctly identified. Each score was entered manually into the computer by the operator. The test resumed by use of alerting dash characters followed by fixation characters on the second display followed in turn by numeric stimuli on the first display. This procedure was continued until the entire trial set was completed.

To familiarize the subject with the presentation of the visual stimuli, each testing session was initiated by a 24-trial demonstration. This run was automatically paced without operator intervention using exposure times of 750, 1000, 1250, and 1500 ms. During this run, the operator emphasized the need for the subject to always directly face the display where the fixation letters would be presented, to rapidly rotate his head toward the eight-digit numeric stimulus display, and to call out as many of the digits that he found possible. This run was then followed by a 48-trial test run using the same exposure times with each exposure time presented 6 times for each direction (left-to-right and right-to-left) of head movement. All trials were scored by the test operator. However, for the six trials associated with each test condition, the lowest two scores were discarded in the final data analysis to minimize the effects of subject errors resulting from inadvertent mispronunciations, brief lapses of attention, et cetera. Thus the data presented in this paper for each exposure time are based on the mean of the best four subject responses.

Experiment 2

With two exceptions, this experiment was identical to Experiment 1. The first difference was that the two LED displays were located 45° to either side of the dead-ahead position. Thus, head movements of 90°, instead of 60°, were required to move from the fixation display to the numeric stimulus display.

The second difference was the addition of a static test immediately after completion of the 48-trial test run sequence. This static test required the subject to face a single TM27 display located in the visual dead-ahead position. The fixation characters and numeric stimulus array

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were presented sequentially on this single display following the same experimental procedures used for the previous tests with the exception that no head movements were required to perform the task. Four exposure times (250, 500, 750, and 1000 ms) were used; each exposure time was presented 6 times, resulting in a total of 24 trials. As before, only the best four scores associated with a given exposure time were used to calculate the mean number of digits correctly identified.

Experiment 3

This experiment, with a few exceptions, was similar to Experiment 1. The first exception was that a total of four displays were used. Two displays were located 45° to the left and right of the visual dead-ahead position thus requiring 90° head movements in the horizontal plane. Two additional displays were located 45° above and below the visual dead-ahead position thus requiring 90° head movements in the vertical plane.

The second exception involved the use of a counter-balanced design to present the horizontal and vertical stimuli. The first phase of the test involved a 24-trial demonstration, a 24-trial practice session, and a 48-trial test run involving head motions made in only one plane (either horizontal or vertical). Following a 2-min rest period, the second phase of the test was inititiated. This phase involved a 24-trial practice session and a 48-trial test run requiring head movements in the other orthogonal plane (either vertical or horizontal).

The experimental design was as follows: The two test phases involved two different stimuli sets identified as A and B. During the first phase of the test, half of the subjects made head movements in the horizontal plane while the other half made movements in the vertical plane; the second phase always involved head movements made in the other plane. Half of the subjects received stimulus set A during the first phase while the other half received set B; the second phase always involved presentation of the other stimulus set. A further condition involved selection of the display that would receive the first fixation sequence presented in either stimulus set A or B. For example, if the first fixation sequence in set A was presented on the left display, a left-to-right head movement would be required to identify the first numeric stimulus. If the first fixation sequence was presented on the right display, a right-to-left head movement would be required to identify the same first numeric stimulus. Accordingly, half of the subjects received their first fixation character on the left display for horizontal head movements while the test began on the right display for the other half. Correspondingly, for vertical head movements, half the subjects received their first fixation character on the upper display while the test began on the lower display for the other half.

Experiment 4

This experiment used the test protocol outlined for Experiment 2 with the exception that each subject was tested on four successive days. The demonstration run was given only on the first testing day.

SUBJECTS

The subjects were volunteers, males, student naval aviators or student naval flight officers, who had recently passed their flight physicals with no known visual or vestibular deficits. A total of 81 individuals volunteered for participation in the study; 25 were assigned to Experiment 1, 25 to Experiment 2, 16 to Experiment 3, and 15 to Experiment 4.

RESULTS AND DISCUSSION

The results of Experiment 1, using the small TM71 display with 60° horizontal head movements, are presented in Table 1. The grand mean, standard deviation of the observations, standard error of the mean, minimum value, and maximum value of the performance scores obtained by the subject group are listed for each of the four exposure times. In this table, and in all following tables, the performance scores derive from the number of stimulus array digits correctly identified during a single trial. The mean datum calculated for each subject, for each direction of head movement, and for each exposure time, represents the average of the four best scores obtained in six trials. In effect, each grand mean in Table 1 derives from a total of 200 observations (100 for each direction of head movement) collected from the study population ($\underline{N}$ = 25). The grand mean scores represent the simple average of the performance scores obtained with the left- and right-directed head movements.

A one-way, repeated measures ANOVA of the grand mean data showed a significant difference ($\underline{F}$(3,24) = 257, $\underline{p}$ < .001) for the exposure time treatment. A Duncan multiple-range comparison of the grand mean data, as depicted in Table 1, indicated that the performance scores obtained at each of the four exposure times were all significantly different ($\underline{p}$ < .01) from each other.

Table 1. Experiment 1 Horizontal Gaze Shift Performance Data for 60° Head Movements for Four Exposure Times Using the Small Character TM71 Displays.

Performance Statistics	Exposure Time (ms)			
	500	750	1000	1250
Grand Mean	0.83 a	2.67 b	3.56 c	4.23 d
SD	0.80	0.65	0.40	0.51
SE	0.16	0.13	0.08	0.11
Minimum	0.00	1.25	3.00	3.50
Maximum	3.00	4.13	4.50	5.38

Means within the same row with the same letter suffix are not significantly different according to Duncan's multiple range test ($\underline{p}$ < .01).

The grand mean data of Experiment 1, plotted in Fig. 1, show that improvements in performance with increased exposure time are more or less linear over the 750 to 1250 ms stimuli intervals. However, a more rapid drop in performance occurs as the exposure time decreases below 750 ms. The minimum and maximum value data presented in Table 1 also reflect

considerable differences in individual performance at each of the four
exposure times as was reported in the original study (2). The results of a
one-way, repeated measures ANOVA and a Duncan multiple-range comparison of
the grand mean data were in essential agreement with those found for the
TM71 displays; significant differences were found for the exposure time
treatment ($F(3,24) = 345$, $p < .0001$), and all four grand mean performance
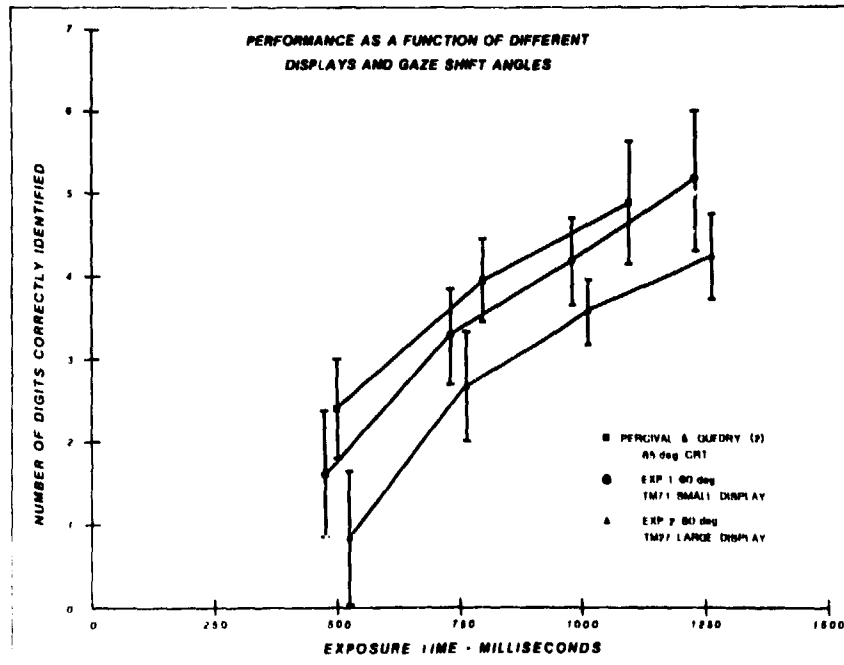scores differed significantly ($p < .01$) from each other.

Figure 1. Mean horizontal gaze performance scores as measured by
Experiment 1, Experiment 2, and Percival and Guedry (2).

During Experiment 1, sample test data were also collected using a
variety of civilian and military subjects who were not associated with the
naval flight training program. Several older subjects (50 to 60 years old)
complained of having visual acuity difficulties with the TM71 small char-
acter LED display. No such difficulties were reported by the flight stu-
dents who participated in Experiment 1. During this period a 37-year-old
Navy helicopter pilot undergoing treatment for hypertension was tested,
and he reported extreme difficulty focusing on the stimulus characters.
Since this test was developed to identify deficiencies in gaze performance
rather than visual acuity, the decision was made to abandon the TM71 small-
character display after Experiment 1 and substitute the TM27 large-charac-
ter display on the following experiments.

The results of Experiment 2, which used the TM27 large-character dis-
play and involved 90° head movements, are summarized in Table 2 using a
format identical to that of Table 1. The grand mean data of Table 2 are
also plotted in Fig. 1. These data indicate a considerable improvement in
performance using this larger display. Again, performance dropped rather
quickly below 750 ms. The minimum and maximum value data of Table 2 also
show the same wide range in individual performance scores with this display
as was observed with the TM71 display.

Table 2. Experiment 2 Horizontal Gaze Shift Performance Data for 90° Head Movements for Four Exposure Times Using the Large Character TM27 Displays.

Performance	Exposure Time (ms)			
Statistics	500	750	1000	1250
Grand Mean	1.61 a	3.27 b	4.18 c	5.17 d
SD	0.76	0.58	0.54	0.87
SE	0.15	0.11	0.11	0.17
Minimum	0.50	2.63	3.50	3.75
Maximum	3.50	5.00	5.63	7.38

Means within the same row with the same letter suffix are not significantly different according to Duncan's multiple range test (p < .01).

The mean and standard deviation of the performance scores associated with the left- and right-directed horizontal gaze shifts used in Experiment 2 are listed at the top in Table 3 for each of the four exposure times and for each direction of head movement. The results of a two-way, repeated measures ANOVA indicated no statistically significant differences in the left/right directional treatment for the grouped data. However, significant differences were present for the exposure time treatment ($F(3,72)$ = 344, p < .0001), as would be expected, and for the treatment interactions ($F(3,72)$ = 11.8, p < .0001). A post hoc means comparison was then performed to determine if any significant differences existed between left and right gaze performance at each of the four exposure times. This analysis used the standard error of the grouped data as derived by Winer (10) to calculate the t statistic according to the Bonferroni (11) method. As indicated in Table 3, significant left/right difference occurred at 500 ms where performance was best for head movements to the right and at 1250 ms where performance was best to the left.

The Pearson correlation r coefficients that relate the performance scores for the two directions of head movements at a given exposure time are also listed in Table 3. These data indicate relatively strong, statistically significant interrelationships between the two directions of head movement for each of the four exposure times.

Figure 1 also contains data obtained from the initial studies of Percival and Guedry (2). These data, extracted from their Fig. 6 plot, were produced by 85° head movements to the right using CRT displays that could generate alphanumeric characters based upon a 16 x 24 point font. Their stimulus characters had a horizontal viewing angle of 14.2 min, a vertical viewing angle of 21.1 min, an inter-digit spacing of 14.2 min, and a stroke width to character height ratio of 1:24. The data plotted in Fig. 1 indicate that though the overall performance scores varied according to the characteristics of each visual display, the performance curve, as a function of exposure time, remained essentially of the same form for all displays.

TABLE 3. Experiment 2 Horizontal Gaze Shift Performance Data for Left and Right Head Movements of 90° for Four Exposure Times Using the Large Character TM27 Displays.

Performance Score Statistics	Exposure Time (ms) and Direction of Head Movement							
	500		750		1000		1250	
	Right	Left	Right	Left	Right	Left	Right	Left
Mean	1.89	1.33	3.24	3.29	4.15	4.21	4.98	5.36
SD	0.80	0.95	0.56	0.65	0.45	0.68	0.82	1.00
r-correlation	0.52**		0.80***		0.77***		0.82***	
df	23		23		23		23	
t-means	6.45*		-0.59		-0.71		-4.51*	
df	72		72		72		72	

* = $p < .05$, ** = $p < .01$, *** = $p < .001$

The performance scores of the Experiment 2 subject group on the static test (a single display in the visual dead-ahead position, which did not require any form of head movement) are presented in Table 4. A one-way, repeated measures ANOVA again indicated significant differences for the exposure time factor ($F(3,24) = 210$, $p < .0001$). Similarly, the Duncan multiple-range comparison test again showed that all four grand means were significantly different ($p < .01$) from each other. These data, and equivalent data collected by Percival and Guedry (2) for the same kind of static testing condition, are plotted in Fig. 2. (The Percival and Guedry data were extracted from their Fig. 2). The resulting plots show an excellent correspondence between the data collected with the two different display systems. The plots also indicate that, numerically, the differences between the two sets of performance scores at a given exposure time do not exceed 0.25 digits over the common stimulus range.

TABLE 4. Experiment 2 Performance Data for Four Exposure Times Using a Single Small Character Model TM27 Display Placed Dead-Ahead of the Subject (No Head Motions Were Required).

Performance Statistics	Exposure Time (ms)			
	250	500	750	1000
Mean Score	2.73 a	3.81 b	4.78 c	5.58 d
SD	0.41	0.45	0.56	0.88
SE	0.08	0.09	0.11	0.17
Minimum	2.00	3.00	3.50	4.75
Maximum	4.00	4.75	6.00	8.00

Means within the same row with the same letter suffix are not significantly different according to Duncan's multiple range test ($p < .01$).

In Experiment 3, the performance of each subject was measured while performing 90° head movements made in the horizontal plane followed by 90° head movements made in the vertical plane (or vice versa). The resulting
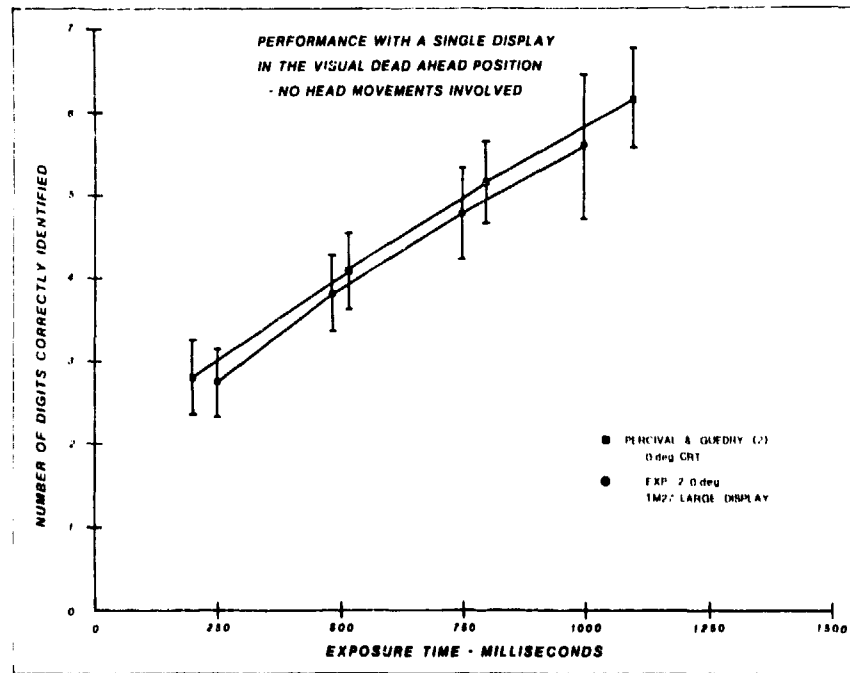
Figure 2. <u>Mean performance scores achieved in Experiment 2, and by Percival and Guedry (2), with a single display positioned directly in front of the subject at eye level.</u>

data are listed in Table 5 and plotted in Fig. 3. A two-way, repeated measures ANOVA showed significant differences only for the exposure time factor ($F(3,45) = 484$, $p < .0001$). Since there was no statistically significant difference for either the direction treatment or the interactions between treatments, a means comparison test was not performed. In effect, the ANOVA results do not indicate any real differences between horizontal and vertical gaze shift performance even though the horizontal scores between 500 and 1000 ms were numerically greater than the vertical scores. The correlation data of Table 5 show that low to moderate, statistically significant correlations exist between the two directions of head movement at all exposure times except 500 ms.

Table 5. Experiment 3 Horizontal and Vertical Gaze Shift Performance Data for Head Movements of 90° for Four Different Exposure Times Using the Large Character TM27 Displays.

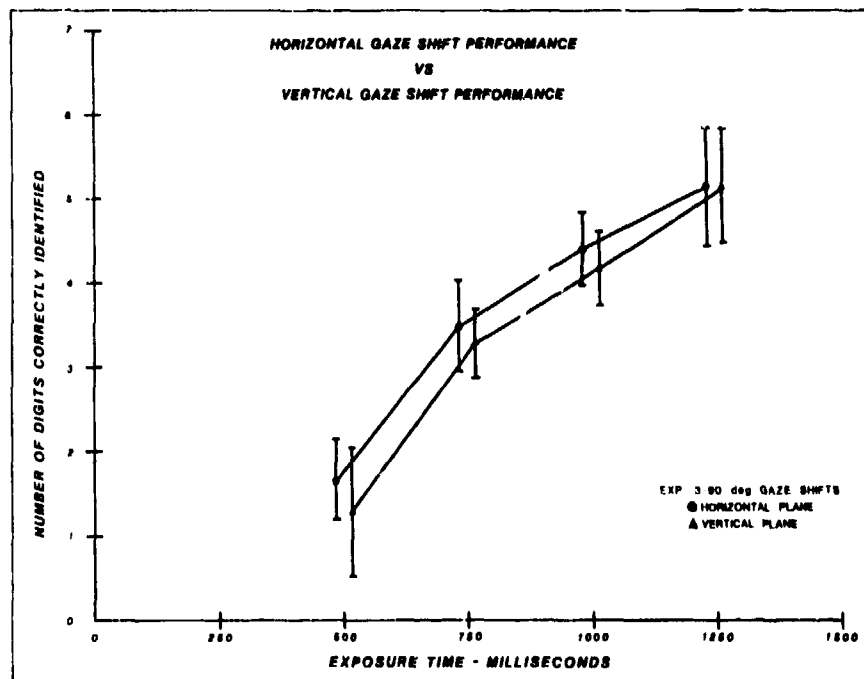| Performance Score Statistics	Exposure Time (ms) and Direction of Head Movement							
	500		750		1000		1250	
	Horiz	Vert	Horiz	Vert	Horiz	Vert	Horiz	Vert
Grand Mean	1.67	1.28	3.49	3.30	4.41	4.19	5.16	5.17
SD	0.48	0.77	0.55	0.41	0.43	0.44	0.71	0.68
r-correlation	0.36		0.49*		0.53*		0.68**	
df		14		14		14		14

* = $p < .05$, ** = $p < .01$

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Figure 3. Experiment 3 data comparing grand mean performance scores derived from 90° bidirectional gaze shifts made in the horizontal plane with those made in the vertical plane.

Table 6 involves the vertical plane data of Experiment 3 and compares the performance scores obtained with downward-directed head movements with those obtained with upward motions. A two-way, repeated measures ANOVA on these data did not show any statistically significant differences for either the direction treatment or the treatment interactions. This would imply that there were no significant differences in gaze performance for either direction of head movement. Only the exposure time treatment was significantly different ($F(3,45)$ = 301, $p < .0001$) as would be expected. Significant correlations between the two directions of vertical gaze shift were present at all exposure times except 750 ms.

TABLE 6. Experiment 3 Vertical Gaze Shift Performance Data for Upward and Downward Head Movements of 90° for Four Exposure Times Using the Large Character TM27 Displays.

Performance Score Statistics	Exposure Time (ms) and Direction of Head Movement							
	500		750		1000		1250	
	Down	Up	Down	Up	Down	Up	Down	Up
Mean	1.19	1.37	3.34	3.25	4.23	4.14	5.16	5.19
SD	0.73	0.95	0.45	0.56	0.49	0.50	0.84	0.67
r-correlation	0.66**		0.28		0.63**		0.65**	
df	14		14		14		14	

** $p < .01$

Table 7 is a similar tabulation of performance scores associated with left- and right-directed head motions made in the horizontal plane by this subject group. A two-way, repeated measures ANOVA of the grouped data indicated the presence of significant differences for the direction treatment ($F(1,15) = 10.1$, $p < .01$) and the exposure time factor ($F(3,45) = 295$, $p < .0001$). Using the Bonferroni method outlined previously, it was found that statistically significant differences in horizontal gaze shift performance occurred at only 500 ms where performance to the right was best. This is in essential agreement with the horizontal gaze shift data of Experiment 2 with the exception that no significant difference occurred at 1250 ms. The correlations between the two directions of horizontal head motion were not as great as those calculated for the equivalent data presented in Table 3.

TABLE 7. Experiment 3 Horizontal Gaze Shift Performance Data for Left and Right Head Movements of 90° for Four Exposure Times Using the Large Character TM27 Displays.

Performance Score Statistics	Exposure Time (ms) and Direction of Head Movement							
	500		750		1000		1250	
	Right	Left	Right	Left	Right	Left	Right	Left
Mean	1.92	1.41	3.51	3.45	4.48	4.32	5.18	5.12
SD	0.39	0.73	0.65	0.63	0.57	0.45	0.99	0.56
r-correlation	0.38		0.46*		0.43*		0.66**	
df	14		14		14		14	
t-means	4.38*		0.53		1.32		0.53	
df	45		45		45		45	

* = $p < .05$, ** = $p < .01$

In Experiment 4, the horizontal gaze shift performance of 15 subjects was measured on 4 successive days to investigate the extent of the learning or practice effects associated with repeated exposure to the test. The mean p' ormance scores and the related standard deviations are listed in Table 8 for each of the four exposure times and for each of the testing days; the means and standard errors of the mean of the same data are plotted in Fig. 4. As would be expected, the mean performance scores improved as a function of time. Application of Duncan's Multiple Range Test to these data indicated that for all four exposure times, performance on Day 2 was significantly better ($p < .05$) than that achieved on Day 1. For the 500-ms exposure time, significant changes in performance did not occur between Days 2 and 3 or Days 3 and 4; the same applies to the 1000-ms stimulus; for 750 and 1250 ms, significant differences did not occur after Day 2. Although learning effects are present, it should be noted that the improvement achieved on Day 4 relative to the Day 1 performance scores amounted to only 0.83, 0.82, 0.72, and 0.67 digits for the 500, 750, 1000, and 1250 ms exposure times, respectively. Relative to studies that require that test performance be stabilized before entering an experimental regimen, it could be projected from these data that minimal changes in performance would occur after 3 testing days.

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TABLE 8. Experiment 4 Horizontal Gaze Shift Performance Data Derived From a Subject Group Tested on Four Successive Days.

Performance Statistics	Exposure Time (ms)			
	500	750	1000	1250
DAY 1				
Grand Mean	1.87 a	3.38 a	4.58 a	5.60 a
SD	0.80	0.48	0.55	0.95
DAY 2				
Grand Mean	2.32 b	3.98 b	4.93 b	6.29 b
SD	0.71	0.66	0.80	1.08
DAY 3				
Grand Mean	2.48 bc	4.13 b	5.05 bc	6.15 b
SD	0.80	0.56	0.67	0.93
DAY 4				
Grand Mean	2.70 c	4.20 b	5.30 c	6.27 b
SD	0.87	0.58	0.88	0.84

Means within the same column with the same letter suffix are not significantly different according to Duncan's multiple range test ($p < .05$).
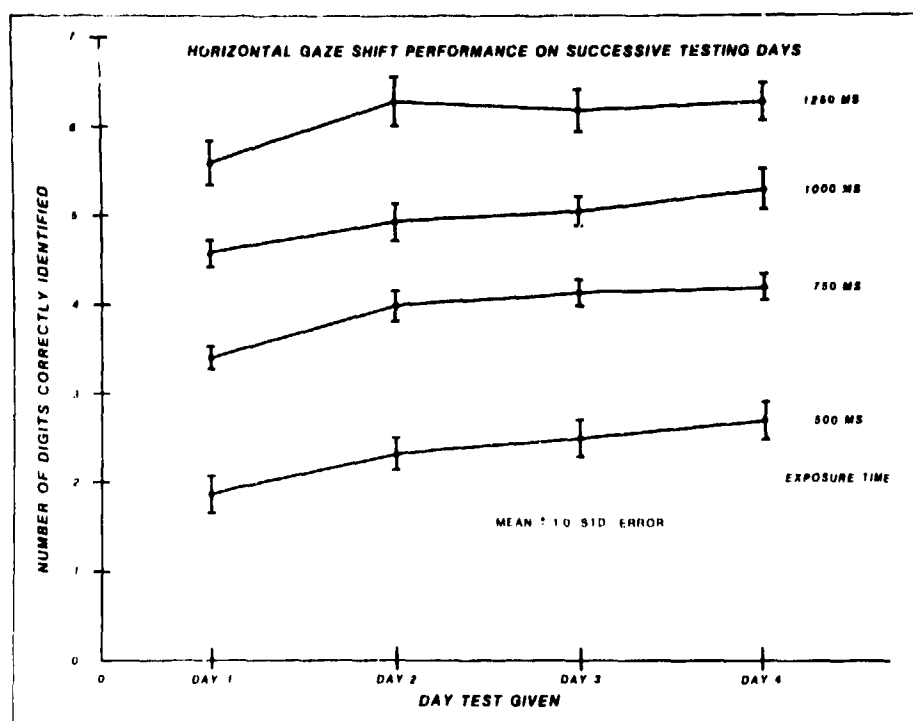

Figure 4. Experiment 4 horizontal gaze shift performance data from a study group tested on four successive days.

SUMMARY

The bidirectional gaze shift data of the present report closely support the unidirectional data of the original study (2) even though the test procedures were not identical and different forms of stimulus displays were used. Most importantly, as with the original study, wide variations in individual performance were observed, particularly at the shorter exposure times. This finding lends considerable support to the concept that such a performance-based test may identify individuals with gaze disorders as well as distinguish pilots with exceptional capabilities in this aspect of visual performance from those with poor gaze-shift capabilities.

RECOMMENDATIONS

The present test configuration involves an eight-digit stimulus array and utilizes four different exposure times. The resulting data allows one to express performance scores (the number of digits correctly identified) as a function of exposure time. The resulting data, though important from a research viewpoint, probably exceed the requirements for either a clinical or aviation selection test of gaze capability. To simplify the testing procedure without compromising its effectiveness, it is recommended that the test be further refined to allow for the determination of a single threshold exposure time for the full identification of a four-digit stimulus array for each direction of head movement. This datum could be derived by using an ascending/descending presentation of exposure times above and below an individual's threshold as originally developed by Bekesy (9). Test artifacts that might arise as a result of individual variations in memory recall with an eight-digit stimulus array would be minimized with the shorter four-digit array. In addition, test performance would be described by a single threshold exposure time. Development of such a test is nearing completion.

REFERENCES

1. McNaughton, G.B., Aircraft Attitude Awareness Workshop, Flight Dynamics Laboratory, Wright-Patterson Air Force Base, OH, 8-10 October 1985.

2. Percival, L.C. and Guedry, F.E., Jr., Development and Evaluation of a Performance-Based Test of Saccadic and Vestibulo-Ocular Control, NAMRL-1306, Naval Aerospace Medical Research Laboratory, Pensacola, FL, January 1984.

3. Barnes, G.R., "Vestibulo-ocular Function During Coordinated Head and Eye Movements to Acquire Visual Targets." Journal of Physiology (London), Vol. 287, pp. 127-147, 1979.

4. Berthoz, A. and Melvill-Jones, G., Adaptive Mechanisms in Gaze Control, Elsevier Science Publishers, New York, NY, 1985.

5. Gresty, M.A. "Coordination of Head and Eye Movements to Fixate Continuous and Intermittent Targets." Vision Research, Vol. 14, pp. 395-403, 1974.

6. King, W.M., Lisberger, S.G., and Fuchs, A.F., "Response of Fibers in
    Medial Longitudinal Fasciculus (MLF) of Alert Monkeys during Hori-
    zontal and Vertical Conjugate Eye Movements Evoked by Vestibular or
    Visual Stimuli." Journal of Neurophysiology, Vol. 39, pp. 1135-
    1149, 1976.

7. Tomlinson, R.D. and Bahra, P.S., "Combined Eye-Head Gaze Shifts in the
    Primate. II. Interactions Between Saccades and the Vestibulo
    Ocular Reflex." Journal of Neurophysiology, Vol. 56, pp. 1558-1570,
    1986.

8. Pola, J. and Robinson, D.A., "Oculomotor Signals in Medial Longitudinal
    Fasciculus of the Monkey." Journal of Neurophysiology, Vol. 41,
    pp. 245-259, 1978.

9. von Bekesy, G., "A New Audiometer." Acta Otolaryngologica, Vol. 35,
    pp. 411-422, 1947.

10. Winer, B.J., Statistical Principles in Experimental Design, Second Ed.
    McGraw Hill Book Co., New York, New York, 1972. Pp. 539-559.

11. Neter, J., Wasserman, W., and Kutner, M.H., Applied Linear Statistical
    Models, Second Ed. Richard D. Irwin, Inc., Homewood, Illinois,
    1985. Pp. 582-584.

OTHER RELATED NAMRL PUBLICATIONS

Percival, L.C. and Guedry, F.E., Jr., Development and Evaluation of a
   Performance-Based Test of Saccadic and Vestibulo-Ocular Control,
   NAMRL-1306, Naval Aerospace Medical Research Laboratory, Pensacola,
   FL, January 1984. (AD# A168 336)*